REMARKS

Claims 1-28 are in the application.

Claims 11-18 are allowed.

Claims 3 and 21 are allowable.

Claims 1-2, and 5-6 and 11-14 are rejected under 35 U.S.C. § 102(b) as being anticipated by Loeppert et al. US 5,870,482.

Claims 7-10, 19-20 and 23-28 are rejected under 35 U.S.C. § 103 as being obvious over Loeppert et al. US 5,870,482.

Claims 4 and 22 are rejected under 35 U.S.C. § 103 as being obvious over Loeppert et al. US 5,870,482 in view of Loeppert et al. US 6,535,460.

All of the claims require that the diaphragm be supported on "torsional springs". A torsional spring is on in which the elastic action is provided as a torque along an axis:

In solid mechanics, torsion is the twisting of an object due to an applied torque. In circular sections, the resultant shearing stress is perpendicular to the radius.

en.wikipedia.org/wiki/Torsion_(mechanics)

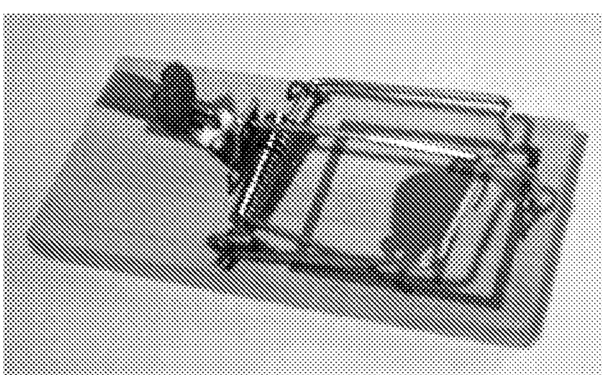
The act of turning or twisting, or the state of being twisted; the twisting or wrenching of a body by the exertion of a lateral force tending to turn one end or part of it about a longitudinal axis, while the other is held fast or turned in the opposite direction; That force with which a thread ...

en.wiktionary.org/wiki/torsion

The strain produced by twisting.

www.nireland.com/bridgeman/Dictionary.htm

Torsion spring (From Wikipedia, the free encyclopedia)
http://en.wikipedia.org/wiki/Torsion_spring



A mousetrap powered by a helical torsion spring

A **torsion spring** is a spring that works by torsion or twisting; that is, a flexible elastic object that stores mechanical energy when it is twisted. The amount of force (actually torque) it exerts is proportional to the amount it is twisted. There are two types. A **torsion**

bar is a straight bar of metal or rubber that is subjected to twisting (shear stress) about its axis by torque applied at its ends. A more delicate form used in sensitive instruments, called a **torsion fiber** consists of a fiber of silk, glass, or quartz under tension, that is twisted about its axis. The other type, a **helical torsion spring**, is a metal rod or wire in the shape of a helix (coil) that is subjected to twisting about the axis of the coil by sideways forces (bending moments) applied to its ends, twisting the coil tighter. This terminology can be confusing because in a helical torsion spring the forces acting on the wire are actually bending stresses, not torsional (shear) stresses.[1] [2]

Torsion coefficient

As long as they are not twisted beyond their elastic limit, torsion springs obey an angular form of Hooke's law:

$$\tau = -\kappa\theta$$

where τ is the torque exerted by the spring in newton-meters, and θ is the angle of twist from its equilibrium position in radians. κ is a constant with units of newton-meters / radian, variously called the spring's **torsion coefficient**, **torsion elastic modulus**, **rate**, or just **spring constant**, equal to the torque required to twist the spring through an angle of 1 radian. It is analogous to the spring constant of a linear spring.

The energy *U*, in joules, stored in a torsion spring is:

$$U = \frac{1}{2}\kappa\theta^2$$

Uses

Some familiar examples of uses are the strong helical torsion springs that operate clothespins and traditional springloaded-bar type mousetraps. Other uses are in the large coiled torsion springs used to counter-balance the weight of garage doors, and a similar system is used to assist in opening the trunk (boot) cover on some sedans. Small coiled torsion springs are often used to operate pop-up doors found on small consumer goods like digital cameras and compact disc players. Other more specific uses:

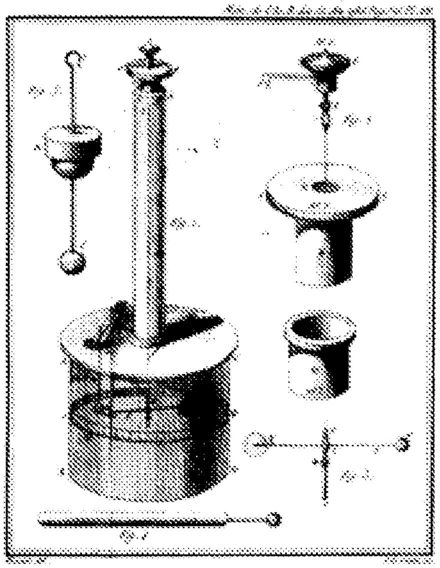
- *Torsion bars* are heavy torsion springs used to support automobile suspension components, allowing those components (which indirectly support the wheels) to move in response to rough roads while allowing a smooth ride in the vehicle.

- The *torsion pendulum* used in torsion pendulum clocks is a wheel-shaped weight suspended from its center by a wire torsion spring. The weight rotates about the axis of the spring, twisting it, instead of swinging like an ordinary pendulum. The force of the spring reverses the direction of rotation, so the wheel oscillates back and forth, driven at the top by the clock's gears.

- The *torsion catapult* or mangonel is a medieval siege engine invented by the ancient Greeks. It uses a torsion spring consisting of twisted ropes to swing an arm that throws a heavy missile at the enemy with great force.

- The *balance spring* or hairspring in mechanical watches is a fine spiral-shaped torsion spring that pushes the balance wheel back toward its center position as it rotates back and forth. The balance wheel and spring function similarly to the torsion pendulum above in keeping time for the watch.
- The *D'Arsonval movement* used in mechanical pointer-type meters to measure electrical current is a type of torsion balance (see below). A coil of wire attached to the pointer twists in a magnetic field against the resistance of a torsion spring. Hooke's law ensures that the angle of the pointer is proportional to the current.
- A *DMD* or digital micromirror device chip is at the heart of many video projectors. It uses hundreds of thousands of tiny mirrors on tiny torsion springs fabricated on a silicon surface to reflect light onto the screen, forming the image.

Torsion balance



Drawing of Coulomb's torsion balance. From Plate 13 of his 1785 memoir.

The **torsion balance**, also called **torsion pendulum**, is a scientific apparatus for measuring very weak forces, usually credited to Charles-Augustin de Coulomb, who invented it in 1777, but independently invented by John Michell sometime before 1783.[3] Its most well-known uses were by Coulomb to measure the electrostatic force between charges to establish Coulomb's Law, and by Henry Cavendish in 1798 in the Cavendish experiment[4] to measure the gravitational force between two masses to calculate the density of the Earth, leading later to a value for the gravitational constant.

The torsion balance consists of a bar suspended from its middle by a thin fiber. The fiber acts as a very weak torsion spring. If an unknown force is applied at right angles to the ends of the bar, the bar will rotate, twisting the fiber, until it reaches an equilibrium where the twisting force or torque of the fiber balances the applied force. Then the magnitude of the force is proportional to the angle of the bar. The sensitivity of the instrument comes from the weak spring constant of the fiber, so a very weak force causes a large rotation of the bar.

In Coulomb's experiment, the torsion balance was an insulating rod with a metal-coated ball attached to one end, suspended by a silk thread. The ball was charged with a known charge of static electricity, and a second charged ball of the same polarity was brought near it. The two charged balls repelled one another, twisting the fiber through a certain angle, which could be read from a scale on the instrument. By knowing how much force it took to twist the fiber through a given angle, Coulomb was able to calculate the force between the balls. Determining the force for different charges and different separations between the balls, he showed that it followed Coulomb's law.

To measure the unknown force, the spring constant of the torsion fiber must first be known. This is difficult to measure directly because of the smallness of the force. Cavendish accomplished this by a method widely used since: measuring the resonant vibration period of the balance. If the free balance is twisted and released, it will oscillate slowly clockwise and counterclockwise as a harmonic oscillator, at a frequency that depends on the moment of inertia of the beam and the elasticity of the fiber. Since the inertia of the beam can be found from its mass, the spring constant can be calculated.

Coulomb first developed the theory of torsion fibers and the torsion balance in his 1785 memoir, *Recherches theoriques et experimentales sur la force de torsion et sur l'elasticite des fils de metal &c*. This led to its use in other scientific instruments, such as galvanometers, and the Nichols radiometer which measured the radiation pressure of light. In the early 1900s gravitational torsion balances were used in petroleum prospecting. Today torsion balances are still used in physics experiments. In 1987, gravity researcher A.H. Cook wrote:

The most important advance in experiments on gravitation and other delicate measurements was the introduction of the torsion balance by Michell and its use by Cavendish. It has been the basis of all the most significant experiments on gravitation ever since.[5]

Torsional harmonic oscillators

For definition of terms see end of section

Torsion balances, torsion pendulums and balance wheels are examples of torsional harmonic oscillators that can oscillate with a rotational motion about the axis of the torsion spring, clockwise and counterclockwise, in harmonic motion. Their behavior is analogous to translational spring-mass oscillators (see Harmonic oscillator#Equivalent systems). The general equation of motion is:

$$I\frac{d^2\theta}{dt^2} + C\frac{d\theta}{dt} + \kappa\theta = \tau(t)$$

If the damping is small, $C \ll \sqrt{\kappa I}$, as is the case with torsion pendulums and balance wheels, the frequency of vibration is very near the natural resonance frequency of the system:

$$f_n = \frac{\omega_n}{2\pi} = \frac{1}{2\pi}\sqrt{\kappa/I}$$

The general solution in the case of no drive force ($\tau = 0$), called the transient solution, is:

$$\theta = Ae^{-\alpha t} \cos(\omega t + \phi)$$

where:

$$\alpha = C/2I$$
$$\omega = \sqrt{\omega_n^2 - \alpha^2} = \sqrt{\kappa/I - (C/2I)^2}$$

Applications

The balance wheel of a mechanical watch is a harmonic oscillator whose resonance frequency f_n sets the rate of the watch. The resonance frequency is regulated, first coarsely by adjusting I with weight screws set radially into the rim of the wheel, and then more finely by adjusting κ with a regulating lever that changes the length of the balance spring.

In a torsion balance the drive torque is constant and equal to the unknown force to be measured F, times the moment arm of the balance beam L, so $\tau(t) = FL$. When the oscillatory motion of the balance dies out, the deflection will be proportional to the force:

$$\theta = FL/\kappa$$

To determine F it is necessary to find the torsion spring constant κ. If the damping is low, this can be obtained by measuring the natural resonance frequency of the balance, since the moment of inertia of the balance can usually be calculated from its geometry, so:

$$\kappa = (2\pi f_n)^2 I$$

In measuring instruments, such as the D'Arsonval ammeter movement, it is often desired that the oscillatory motion die out quickly so the steady state result can be read off. This is accomplished by adding damping to the system, often by attaching a vane that rotates in a fluid such as air or water (this is why magnetic compasses are filled with fluid). The value of damping that causes the oscillatory motion to settle quickest is called the critical damping C_c:

$$C_c = 2\sqrt{\kappa I}$$

Definition of terms		
Term	**Unit**	**Definition**
θ	radians	Angle of deflection from rest position
I	$\mathrm{kg\ m^2}$	Moment of inertia
C	$\mathrm{kg\ m^2\ s^{-1}\ rad^{-1}}$	Rotational friction (damping)
κ	$\mathrm{N\ m\ rad^{-1}}$	Coefficient of torsion spring
τ	$\mathrm{N\ m}$	Drive torque
f_n	Hz	Undamped (or natural) resonance frequency

ω_n	$\mathrm{rad\,s^{-1}}$	Undamped resonance frequency in radians
f	Hz	Damped resonance frequency
ω	$\mathrm{rad\,s^{-1}}$	Damped resonance frequency in radians
α	$\mathrm{s^{-1}}$	Reciprocal of damping time constant
ϕ	rad	Phase angle of oscillation
L	m	Distance from axis to where force is applied

See also

- Beam (structure)
- Bending moment
- Torsion bar suspension

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2. ^ Bandari, V. B. (2007), *Design of Machine Elements*, Tata McGraw-Hill, pp. 429, ISBN 0070611416, http://books.google.com/?id=f5Eit2FZe_cC&pg=PA429
3. ^ McCormmach, R.; Jungnickel, C. (1996), *Cavendish*, American Philosophical Society, pp. 335–344, ISBN 0-87169-220-1, http://books.google.com/?id=EUoLAAAAIAAJ
4. ^ Cavendish, H. (1798), "Experiments to determine the Density of the Earth", in MacKenzie, A.S., *Scientific Memoirs, Vol.9: The Laws of Gravitation*, American Book Co., 1900, pp. 59–105
5. ^ Cook, A.H. (1987), "Experiments in Gravitation", in Hawking, S.W. and Israel, W., *Three Hundred Years of Gravitation*, Cambridge University Press, pp. p.52, ISBN 0521343127

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- *Charles Augustin de Coulomb biography, Chemistry Dept.*, Hebrew Univ. of Jerusalem, http://www.geocities.com/bioelectrochemistry/coulomb.htm, retrieved August 2, 2007. Shows pictures of the Coulomb torsion balance, and describes Coulomb's contributions to torsion technology.

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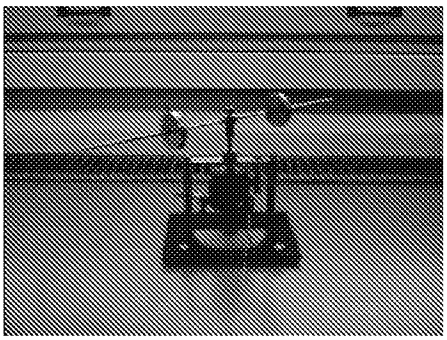
- *Torsion balance, Virtual Geoscience Center*, Society of Exploration Geophysicists, http://www.mssu.edu/seg-vm/pict0349.html, retrieved 2007-08-04. Description of how torsion balances were used in petroleum prospecting, with pictures of a 1902 instrument.

- *Charles Augustin de Coulomb*, **6**, Werner Co., 1907, p. 452, http://books.google.com/?id=IAwEAAAAYAAJ&pg=PA452

External links



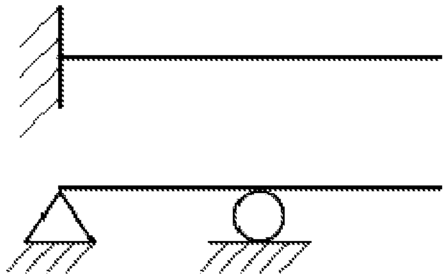
Video of a model torsion pendulum oscillating

- Torsion balance interactive java tutorial
- Torsion spring calculator
- Big G measurement, description of 1999 Cavendish experiment at Univ. of Washington, showing torsion balance
- Four torsion balances used in contemporary physics experiments
- How torsion balances were used in petroleum prospecting
- Mechanics of torsion springs
- Solved mechanics problems involving springs (springs in series and in parallel)

In contrast, cantilever systems impose a shear stress on the supporting member:

Cantilever (From Wikipedia, the free encyclopedia)

http://en.wikipedia.org/wiki/Cantilever



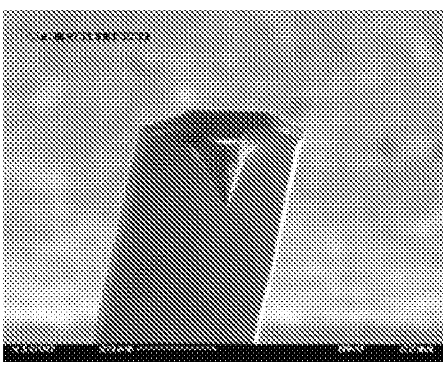
A schematic image of two cantilevers. The top example has a full moment connection (like a horizontal flag pole bolted to the side of a building). The bottom example is created by an extension of a simply supported beam (such as the way a diving-board is anchored and extends over the edge of a swimming pool).

A **cantilever** is a beam supported on only one end. The beam carries the load to the support where it is resisted by moment and shear stress.[1] Cantilever construction allows for overhanging structures without external bracing. Cantilevers can also be constructed with trusses or slabs.

This is in contrast to a simply supported beam such as those found in a post and lintel system. A simply supported beam is supported at both ends with loads applied between the supports.

*   *   *

In microelectromechanical systems



SEM image of a used AFM cantilever

Cantilevered beams are the most ubiquitous structures in the field of microelectromechanical systems (MEMS). An early example of a MEMS cantilever is the Resonistor[4][5], an electromechanical monolithic resonator. MEMS cantilevers are commonly fabricated from silicon (Si), silicon nitride (SiN), or polymers. The fabrication process typically involves undercutting the cantilever structure to *release* it, often with an anisotropic wet or dry etching technique. Without cantilever transducers, atomic force microscopy would not be possible. A large number of research groups are attempting to develop cantilever arrays as biosensors for medical diagnostic applications. MEMS

cantilevers are also finding application as radio frequency filters and resonators. The MEMS cantilevers are commonly made as unimorphs or bimorphs.

Two equations are key to understanding the behavior of MEMS cantilevers. The first is *Stoney's formula*, which relates cantilever end deflection δ to applied stress σ:

$$\delta = \frac{3\sigma(1-\nu)}{E}\left(\frac{L}{t}\right)^2$$

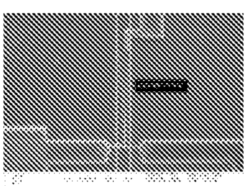
where ν is Poisson's ratio, E is Young's modulus, L is the beam length and t is the cantilever thickness. Very sensitive optical and capacitive methods have been developed to measure changes in the static deflection of cantilever beams used in dc-coupled sensors.

The second is the formula relating the cantilever spring constant k to the cantilever dimensions and material constants:

$$k = \frac{F}{\delta} = \frac{Ewt^3}{4L^3}$$

where F is force and w is the cantilever width. The spring constant is related to the cantilever resonance frequency ω_0 by the usual harmonic oscillator formula $\omega_0 = \sqrt{k/m}$. A change in the force applied to a cantilever can shift the resonance frequency. The frequency shift can be measured with exquisite accuracy using heterodyne techniques and is the basis of ac-coupled cantilever sensors.

The principal advantage of MEMS cantilevers is their cheapness and ease of fabrication in large arrays. The challenge for their practical application lies in the square and cubic dependences of cantilever performance specifications on dimensions. These superlinear dependences mean that cantilevers are quite sensitive to variation in process parameters. Controlling residual stress can also be difficult.



MEMS cantilever in resonance[6]

*   *   *

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2. ^ IStructE The Structural Engineer Volume 77/No 21, 2 November 1999. James's Park a redevelopment challenge

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5. ^ R.J. Wilfinger, P. H. Bardell and D. S. Chhabra: The resonistor a frequency selective device utilizing the mechanical resonance of a silicon substrate, IBM J. 12, 113-118 (1968)

6. ^ P. C. Fletcher, Y. Xu, P. Gopinath, J. Williams, B. W. Alphenaar, R. D. Bradshaw, R. S. Keynton, "Piezoresistive Geometry for Maximizing Microcantilever Array Sensitivity," presented at the IEEE Sensors, Lecce, Italy, 2008.

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Thus, the claims require that the diaphragm deflection be transduced into a twisting moment on a “torsional spring”. This transduction is by way of a stiff edge supporting the diaphragm about an axis of deflection, with the torsional springs supporting the stiff edge for rotation about that axis.

Loeppert et al. ‘482 teach a materially different system, in which the diaphragm is supported by a cantilever structure. See, e.g., Col. 4, lines 49-63:

> The performance of the cantilevered microphone 10 illustrated in FIG. 1 tends to deviate from the optimum in two respects. **First, because of the aforementioned compliance properties of cantilevers versus edge-clamped diaphragms, this cantilever structure as shown in FIG. 1 is actually so compliant that it overloads at the highest sound pressures encountered in certain microphone applications.** Second, the cantilevered diaphragm of FIG. 1 fabricated from integrated circuit thin film materials as described above tend to curl due to three sources of unrelieved stress: (1) stress gradients through the thickness of the thin film remaining from deposition; (2) differential stresses caused by the addition of thin chrome or other metallization to the surface of the diaphragm; and (3) unrelieved film stresses at the fixed edge 12a, where the diaphragm 12 is anchored.

Note that the stiffness of the lateral supporting edge of Loeppert ‘482 is qualitatively different than either the present claimed structures, the stiff edge and the torsional springs, the since the Loeppert ‘482 edge is stationary and fixed to the adjacent

support, while in accordance with the present claims, the “stiffened edge” or “stiff edge structure” itself rotates about the deflection axis, and is supported by the torsional springs. Thus Loeppert et al. ‘482 provide a materially different structure, operating according to materially different physical principles, to achieve a different result. It is believed that at least the higher order vibrational modes of a cantilever supported diaphragm and a torsionally supported diaphragm are distinct. There is thus no equivalence in function, or structure between the cantilever support of Loeppert ‘482, wherein the supporting edge itself absorbs the bending strain due to deflection of the diaphragm, and the presently claimed structure, in which the deflection of the dasphragm is converted into a torsional strain on the torsional springs.

Loeppert ‘460 does not remedy the deficiencies in this regard of Loeppert et al. ‘482. Therefore, it is respectfully requested that the rejections be withdrawn.

Claims 2, 4-10, 19-20 and 22-28 are believed to be patentable for at least the same reasons as claims 1 and 19, respectively.

It is therefore respectfully submitted that the rejections should be withdrawn. The examiner is respectfully invited to call the undersigned if any issues remain outstanding.

Respectfully submitted,

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